

Measuring the effectiveness of research-based curriculum at a university serving a diverse student population

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California State University Fullerton is a regional comprehensive university that serves a diverse student population. Over half of the undergraduate students at CSUF are members of minority groups, and just under half spoke a language other than English at home while growing up. We have tested research-based curricular materials, including Tutorials in Introductory Physics, in courses at CSUF. In some cases, these materials are successful. However, in many cases student outcomes are significantly different from those reported at large research universities. Informally, many faculty believe that the student population at CSUF is significantly different from those at more selective universities. In what ways can the tools of PER be used to measure, describe, and understand the differences between student populations? Are the standard methods of PER suitable for answering questions of this type?

MOTIVATION FOR STUDY

Many graduates of PER programs find themselves teaching in settings that are considerably different from the research universities where they were trained. At the same time, curricula developed at selective national research universities are being adopted by departments at other types of institutions. Materials developed and tested with one population of students are thus used with groups of students that may be considerably different.

The author and the physics department at California State University Fullerton (CSUF) have tested research-based curricula in various physics courses. Results have been mixed. In some cases, these materials appear to be effective. In others, student performance is more disappointing.

CONTEXT FOR RESEARCH

This study was performed in the context of several courses at CSUF, a public comprehensive university serving a diverse student population. The student population is described in more detail below.

Instructional setting

CSUF has two introductory physics sequences, one algebra-based (two semesters), and one calculus-based (three semesters). We abbreviate the former ABM (algebra-based mechanics), and the latter, CBM (calculus-based mechanics). In both cases, the first semester of the sequence focuses on mechanics, though

ABM typically also includes 1-3 weeks of study of thermal physics and/or fluids. Both sequences have three hours of lecture each week, with no small-group recitation sections. Each sequence has an associated three-hour lab, which is required for CBM and optional for ABM. For the most part, both courses are traditionally taught, though individual lecture instructors have used research-based curricula.

The study author tested *Tutorials in Introductory Physics (TiIP)* [McDermott 2002] in his sections of CBM during Fall semesters 1999, 2000, and 2001. Because there is no small-group recitation, the tutorials were used in lecture one day a week in an interactive lecture format. Students worked in groups and the instructor circulated around the room, periodically interrupting for whole-class discussions. Class sizes were small, ranging from 8 to 40.

In addition, the labs for both ABM and CBM were modified from a largely traditional verification laboratory to include a sequence of four MBL labs on kinematics and Newton's laws. These labs were locally adapted from *TiIP* and *RealTime Physics* [Sokoloff, Thornton & Laws 1999].

Demographics

The California State University system is the nation's largest public university, and serves diverse student populations characteristic of the state as a whole. At CSUF, Fall 2002 enrollment was 32,143 students, 60% of whom

are female. The ethnicity of undergraduate students was 34% white, 25% Latino/a, 18% Asian, 5% Pacific Islander, 3% African-American, with 11% declining to state.

Many CSUF students have social and educational backgrounds that are quite different from students at other universities. For example, 75% are employed, working an average of 25 hours per week, and over 20% have one or more dependents. Over half come from families in which neither parent graduated from college. Just under half spoke a language other than English at home while growing up.

The study courses tend to be fairly similar to the university population as a whole. For example, students in the Fall 2001 section of calculus-based mechanics were 35% white, 30% Latino, 25% Asian (including Pacific Islander), with 10% unknown / declining to state. In this section 40% of students were female.

Pretest results

For the purposes of this report, student assessment data will focus on a small subset of course topics. We will report data from the Force Concept Inventory (FCI) as well as from open-ended ungraded quiz questions related to specific portions of *TiIP*, specifically kinematics and Newton's laws.

The FCI was given to several sections of the mechanics laboratory in the first week of the Fall 2000 semester. However, not all of these sections gave the FCI again as a posttest, so matched data is somewhat limited. The FCI was given as both pre- and post-test in several sections of the laboratory in Fall 2002. Fall 2000 pretest scores on the FCI were 7.7 ($N = 62$) for the ABC and 10.1 ($N = 52$) for the CBC. In 2002, the averages were 8.4 for the ABC ($N = 88$) and 11.2 for the CBC ($N = 22$). These pretest scores are quite low compared to the data reported in national reports (e.g, Hake 1998).

In the sections of the CBC using *TiIP*, students also periodically completed ungraded quizzes, either online or on paper. These ungraded quizzes were typically closely related to the pretests developed as part of *TiIP* (which are published in the *TiIP* instructor's guide). Student performance on these pretests was often quite poor. For example, in the Fall 2000 semester we gave two pretests that required

students to draw acceleration vectors, one for the movement of a ball moving up and down a ramp, one for an object moving along an oval shaped track with constant speed. On both pretests, we found that none of the students ($N = 12$) gave correct answers, despite having completed some lecture instruction on the topic of acceleration.

GOOD NEWS

Student learning data

After completing a series of tutorials on kinematics and Newton's laws, student performance on certain open-ended questions was reasonably good. We will focus on two parts of one specific question posed on the course final exam, Fall 2001.

In the first part of the question, students ($N = 39$) were asked to draw velocity, acceleration, and net force vectors for an object moving in uniform circular motion. Nearly all students, 95% of the class, drew correct velocity and acceleration vectors, in contrast to essentially 0% on the pretest. Moreover, 65% of the class drew correct vectors for the net force on the object. Again, this result contrasts with the 75% from this class who had associated net force with velocity rather than acceleration in a simpler, one-dimensional pretest question.

Student subjective evaluations

In addition to student learning data, we gave a questionnaire asking for subjective evaluation of the tutorials in one semester of CBM. The average rating for the tutorials was 4.2 on a five point scale, higher than any of the other parts of the course surveyed. Half of the students responding ($N = 18$) gave the tutorials the highest possible rating. Student comments on an open-ended question were also favorable, with 7 out of 18 students stating that they valued the increased emphasis on concepts and 5 out of 18 students stating that they valued the interaction with peers as an important learning tool.

BAD NEWS

Student learning

Whereas some open-ended questions showed positive results, others revealed significant deficiencies in student understanding, even after completion of tutorials and/or

modified labs. In some cases, these results suggest that the apparent good news reported above in fact is somewhat superficial. Below we report results from the final exam for the Fall 2001 section of CBM ($N = 39$).

We posed a question called the Three Pucks question based on the tutorial *Dynamics of Rigid Bodies* from *TiIP*. In this question, which tests student understanding of Newton's second law, forces of the same magnitude are applied to each of three identical pucks. The forces are applied at different locations, and students are asked to compare the center-of-mass accelerations of the three pucks. This question proves to be quite difficult, with only 10% of students answering correctly on pretests at the University of Washington. We did not use the Three Pucks question as a pretest at CSUF. On the final exam, after a full semester of tutorials including *Dynamics of Rigid Bodies*, only 10% of students answered correctly. In contrast, student success after the tutorial at UW is approximately 40% [Ortiz 2001].

Another question on the same final involved drawing acceleration vectors in the context of two-dimensional motion with varying speed (namely, a falling pendulum). Whereas 95% of students drew correct acceleration vectors in the case of uniform circular motion, only 25% did so in the case of the speeding-up pendulum. About 50% of the students drew acceleration vectors that were radial, suggesting that many students may have simply memorized the result from motion with constant speed and incorrectly generalized this result.

The FCI results for sections completing modified labs were similarly disappointing. The normalized gain $\langle g \rangle$ for the Fall 2000 course was only 0.18 for the students in ABM, and 0.10 for those in CBM. Results for the Fall 2002 administration of the FCI are similar, with gain factors of 0.13 in ABM and 0.17 in CBM. These results are very low compared to those reported in Hake [1998] for any kind of instruction, standard or interactive-engagement. These results include only two students the section of the course using *TiIP*, too few for any meaningful conclusions.

Student subjective evaluations

Whereas student subjective evaluations were overall quite positive, and many students pointed to the value of their emphasis on conceptual understanding, there were some troubling signals. For example, several of the students who ranked the tutorials most highly answered that the tutorials were valuable mostly because they helped with the exams. One such student wrote, "They were almost like the test but in a different format and a bit easier."

Some of the students who rated the tutorials least valuable commented on their difficulty and the time they took to complete. One wrote, "the tutorials did not always go with what we were learning and were advance in complex questions." Other students apparently preferred other uses of class time: "The tutorials again were good for acquainting us with the concepts but seemed to take up to much time which could of been used more productively."

POSSIBLE INTEPRETATIONS

In some cases, student performance after use of research-based curricula was disappointing. It should be emphasized that small sections and incomplete data may contribute to a distorted picture of student performance that would not hold up to greater scrutiny. However, subjective assessments by instructors suggest that some of the difference in student performance may be due to the very different student population at CSUF. In this section we briefly examine possible interpretations of the differences. Of course, a portion of the difference may also be due to simple chance.

Implementation deficiencies

As noted above, the implementation of research-based curricula was somewhat different than the 'standard' use of these materials. *TiIP* was used in a lecture setting instead of a small-group recitation setting. However, the author has used tutorials in an interactive lecture setting successfully and is very experienced with the materials.

The author's subjective judgment is that the content of several of the tutorials, particularly those on vector kinematics, were especially challenging for the CSUF students. These tutorials all require long chains of reasoning and

complicated arguments using limiting cases. It may be that the relatively poor performance on some assessment questions from these tutorials reflects those difficulties. However, results were similarly poor on the question testing the more concrete and hand-on tutorial *Dynamics of Rigid Bodies*.

The revised sequence of labs apparently had little impact on student learning. However, the MBL labs were admittedly imperfect adaptations of published materials. Perhaps more importantly, TA preparation was limited to a single three-hour meeting for the entire lab sequence.

Academic background

It may be that deficiencies in academic background led to the difficulties described above. As we pointed out above, the FCI pretest scores for CSUF students are low compared to previously published data. We found no significant correlation between pretest and gain scores on the FCI (e.g., a correlation coefficient of 0.1 for Fall 2000 data). However, we did not measure mathematical or reasoning background, and other researchers have published results suggesting that both factors may significantly impact student learning [Meltzer 2002, Dancy 2002]. Above, we noted that several students commented on the difficulty of the tutorials. Deficiencies in mathematical or overall reasoning skills may have been particularly important for those tutorials requiring long chains of mathematical reasoning, particularly those on vector kinematics.

Epistemological expectations

There is an emerging body of work studying the epistemological expectations students have for physics courses. Responses to the subjective survey suggest that some students value the tutorials for reasons that may not please instructors (e.g., they are similar to test questions). Subjectively, the author has noted a preference among some students for memorization (e.g., use of flash cards).

While we have not administered the MPEX survey of epistemological expectations [Redish 1998] to either of the courses in this study, we did give it to one section of a course for non-science majors ($N = 40$). These students were much less likely than those at large universities

to agree with experts on the Independence, Math, and Coherence clusters of the MPEX. It is not clear whether these results are applicable to the courses in this study.

NEED FOR ADDITIONAL RESEARCH

The relatively poor performance of CSUF students after research-based instruction raises several questions. To what extent are the differences in student populations responsible for the differences in performance? Can the differences in populations be measured by the standard tools of PER? CSUF students have very low pretest scores, but are these low scores alone enough to account for the relatively low improvements? Are there 'hidden variables' like mathematical or reasoning ability that account for the differences? Or do the students at CSUF have epistemological expectations that do not allow them to succeed in an interactive-engagement classroom?

At present, our data are insufficient for resolving these issues. We present these results in part to promote discussion of appropriate tools and methodologies for these questions. There are also larger questions about the purpose of introductory physics courses and the overall needs of students in these course, which this study is not positioned to address.

References:

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